PAT-NO: JP405332876A

DOCUMENT-IDENTIFIER: JP 05332876 A

TITLE: APPARATUS AND METHOD FOR TESTING VIBRATION OF STRUCTURE

PUBN-DATE: December 17, 1993

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APPL-NO: JP04143950

APPL-DATE: June 4, 1992

INT-CL (IPC): G01M007/02, G01M019/00 , G05D019/02 , F16F015/02

ABSTRACT:

PURPOSE: To obtain a testing apparatus and a testing method, by which the testing time is shortened by decreasing the computing amount of numerical computation, and expanding the time spacing of the numerical computation in the vibration testing apparatus, wherein the shaking test for an actual substance and the numerical computation are combined.

CONSTITUTION: An actuator 2 is attached to a partial-structure model 1 of an object to be shaken. The actuator is controlled with a control device 8. The mode vector of a total structure using the linearized model of the partial structure model 1 is inputted into a digital computer 7. Here, the modes,

which are not required for response computation, are removed. The virtual external force is computed based on the difference between the computed value of a load measuring device 3 and the computed value of reaction using the measured value of a displacement measuring device 4. The vibration response at a shaking point is computed together with the external force. The results are inputted into the control device 8. The computing amount of the vibration responses is decreased by removing the unnecessary modes, and the time spacing, which is determined by the shortest natural period, can be made large.

DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[Industrial Application] this invention relates to the vibration tester of the structure of the structure, and its method, and in some vibration tests of the structure, and the vibration test of the structure performed combining the oscillating response numerical analysis of other portions, when the flexibility of a numerical-analysis model is large, it relates to the vibration tester of the suitable structure, and its method. Moreover, it is related with the vibration tester of the suitable structure to perform the above-mentioned examination by the real time, and its method.
[0002]
[Description of the Prior Art] the vibration test by some actuators of the structure and the vibration test of the structure performed combining the oscillating response numerical analysis of other portions are called a "semi- dynamic test" or "temporary dynamic test" -- having -- **** -- for example, the Architectural Institute of Japan paper report collection -- an example of the system is indicated by 83 pages from 77 pages of the 229 No. (Showa 50) Moreover, there is also technology given [JP,61-34438,A, JP,61-132835,A, and JP,62-220831,A each] in an official report. The technique of a centered-difference method is used for numerical calculation in these testing devices.
[0003]
[Problem(s) to be Solved by the Invention] if the model of numerical calculation has large-scale flexibility here -- every step -- in order [being large-scale] to carry out matrix calculation -- machine time -- starting -- the time serration on calculation -- a vibration test -- ** 100 times the number [several times to] of this of expanding -- the dynamic examination had to be performed
[0004] Moreover, although performing response calculation in mode space is proposed in JP,62-220831,A, it is required to perform characteristic value analysis for every step, and big machine time is needed similarly.
[0005] moreover, the Architectural Institute of Japan paper report collection -- by the centered-difference method or the other numerical calculation technique, there is maximum of time [to become settled from the natural period for analysis for performing numerical analysis stably] serration as indicated by 124 pages from 115 pages of the 288 No. (Showa 55) Although the object structure hardly affected the oscillating response with the actual oscillation mode with many flexibility when the minimum natural period was very short, an examination and numerical calculation needed to be performed by time serration shorter than the maximum which becomes settled from the minimum natural period, and when it was a semi- dynamic test, there was a trouble that test time became long.
[0006] Moreover, when the force not only about the force about a variation rate but speed or acceleration joins the reaction force which joins other portions from the substructure object for a vibration test, the need has excited the substructure by the same time serration as the time serration on numerical calculation, i.e., real-time excitation. However, it was difficult for difficult hatchet realization to perform big computational complexity for a short time as above-mentioned.
[0007] In the trouble which showed the purpose of this invention above, i.e., the vibration test by some actuators of the structure, and the vibration test of the structure performed combining the oscillating response numerical analysis of other portions By solving that it is necessary to make time serration in numerical calculation small since the computational complexity at the time of being aimed at a large-scale numerical model increasing and the maximum of time serration become settled by the minimum natural period It is in offering the testing device and method of shortening test time in a semi- dynamic test. Moreover, offering the testing device and method of enforcing easily has a real-time excitation examination.
[0008] Moreover, other purposes of this invention are to offer the method for carrying out without numerical calculation emitting in the above-mentioned vibration test.
[0009]
[Means for Solving the Problem] The above-mentioned purpose linear-model-izes reaction force from the substructure model for excitation as reaction force proportional to the variation rate of an exciting point. Characteristic value

analysis is performed combining the model and the numerical model used for numerical calculation. Judging from excitation conditions etc., only the required mode is chosen among the oscillation modes acquired from here, and it is attained by considering as the vibration tester of the structure by the digital computer, actuator and variation rate which recorded the algorithm shown below, and the combination of a load cell. In addition, time serration on calculation is set to deltat.

[0010] (1) the exciting point in the time t on calculation -- the reaction force {q} of the substructure model in the exciting point over a variation rate, and an exciting point -- measure a variation rate

(2) Calculate the calculated value {q'} of reaction force with a linear model from exciting point displacement.

(3) The difference of {q} and {q'} is made into the external force {deltaq} in an exciting point, and it changes into the reduction mode space which uses this for calculation.

(4) The external force {f} defined in advance is changed into reduction mode space.

(5) Calculate the response of time t+delta t in each mode to {deltaq} and {f} in reduction mode space.

(6) Change the response in each mode and compute the displacement response of the exciting point in physical space.

(7) Drive an actuator and apply the calculated variation rate to a substructure model.

It returns to (8) and (1).

[0011] Moreover, the force which is proportional to the variation rate of an exciting point about the reaction force from the substructure model for excitation in order to perform a real-time excitation examination, It linear-model-izes as the sum of the force proportional to the speed of an exciting point, and the force proportional to the acceleration of an exciting point. Characteristic value analysis is performed combining the model and the numerical model used for numerical calculation. Judging from excitation conditions etc., only the required mode is chosen among the oscillation modes acquired from here. It is attained by considering as the vibration tester of the structure by the combination of the digital computer, the actuator, and displacement measurement equipment which recorded the algorithm shown below, and realizing the oscillating response after calculated deltat with an actuator after deltat of the time when reaction force and the oscillating response were measured.

[0012] (1) the exciting point in Time t -- the reaction force {q} of the substructure model in the exciting point over a variation rate, and an exciting point -- a variation rate -- measure - speed and acceleration

(2) Calculate the calculated value {q'} of reaction force with a linear model from exciting point displacement, speed, and acceleration.

(3) The difference of {q} and {q'} is made into the external force {deltaq} in an exciting point, and it changes into the reduction mode space which uses this for calculation.

(4) The external force {f} defined in advance is changed into reduction mode space.

(5) Calculate the response of time t+delta t in each mode to {f} and {deltaq} in reduction mode space.

(6) Change the response in each mode and compute the oscillating response of the exciting point in physical space.

(7) Drive an actuator and add to a substructure model so that the oscillating response in the calculated exciting point may be realized to time t+delta t.

It returns to (8) and (1).

[0013] Moreover, calculation of a mode oscillating response analysis portion is accelerable by making a digital computer into a parallel computer.

[0014] Moreover, in order to perform numerical calculation stably, it is attained by examining on the conditions with which the characteristic value and machine time serration in the mode are filling the stability condition which becomes settled from the numerical calculation technique.

[0015] The vibration tester of the structure of the structure of this invention carries out object modeling of some structures using thing or a model, other portions are numerical-model-ized, and it is an actuator (a piece or two or more actuators.) to a boundary portion with the numerical model of an object model. It is below the same. It attaches, it has the control unit of an actuator, the equipment which measures the reaction force from the object model produced in an actuator, the equipment which measures the variation rate of the exciting point by the actuator, and the digital computer which calculates the displacement response of a numerical model, the reaction-force measured value by the reaction-force measuring device and the displacement-measurement value by displacement measurement equipment are inputted into a digital computer, and it is characterized by to output the oscillating response calculated value of a digital computer to the control unit of an actuator.

[0016] In this case, numerical-model-izing which is proportional to the variation rate of an exciting point about the reaction force from an object model (It is hereafter called an object model reaction force numerical model.) The arbitrary piece or two or more arbitrary vectors of the normal-mode-of-vibration vectors of the whole structure which were calculated by carrying out, The matrix which changes the physical space using those vectors into mode space, It is desirable to have a means to input into a digital computer the matrix which changes mode space into physical space, and an object model reaction force numerical model. further a digital computer The reaction force from the object

model generated in an actuator and the variation rate of an exciting point are measured. The calculated value of reaction force is computed with an object model reaction force numerical model from a displacement measurement value. The difference of reaction force measured value and reaction force calculated value is made into the external force value which joins an exciting point. the sum of an external force value and a known external force value It changes into the external force value in mode space by the physical space mode space conversion matrix. The mode response value after a fixed time unit is calculated with this mode space external force value. It is desirable that it is what repeats to output an excitation signal so that a mode space response value may be changed by the mode space physics space conversion matrix, the variation rate after fixed time in an exciting point may be calculated and the variation rate may be realized to an actuator, and performs it.

[0017] Moreover, the vibration tester of the structure of this invention carries out object modeling of some structures using thing or a model. Other portions are numerical-model-ized and an actuator is attached in a boundary portion with the numerical model of an object model. The control unit of an actuator, The equipment which measures the reaction force from the object model produced in an actuator, the equipment which measures the variation rate of the exciting point by the actuator, the equipment which measures speed, the equipment which measures acceleration, or its combination, It is characterized by having the digital computer which calculates the oscillating response of a numerical model, a means to input reaction force measured value, and displacement, speed and an acceleration-measurement value into a digital computer, and a means to output the oscillating response calculated value of a digital computer to the control unit of an actuator.

[0018] In this case, it sets. The arbitrary piece or two or more arbitrary vectors of the normal-mode-of-vibration vectors of the whole structure calculated in the reaction force from an object model by numerical-model(object-model-reaction-force-numerical model)-turning as the sum of the reaction force proportional to the oscillating response equipped with the measuring device among displacement, speed, and acceleration of an exciting point, It is desirable that it is about a means to input into a digital computer the matrix which changes the physical space using the vector into mode space, the matrix which changes mode space into physical space, and an object model reaction force numerical model.

[0019] Moreover, the digital computer in this case measures the oscillating response with which the metering device is equipped among the reaction force from the object model generated in an actuator for every fixed time, and displacement, speed and acceleration of an exciting point. The calculated value of reaction force is computed with an object model reaction force numerical model from measured value. The difference of reaction force measured value and reaction force calculated value is made into the external force value which joins an exciting point. the sum of an external force value and a known external force value It changes into the external force value in mode space by the physical space mode space conversion matrix. The mode response value after a fixed time unit is calculated with this mode space external force value. By changing a mode space response value by the mode space physics space conversion matrix, calculating the oscillating response after fixed time in an exciting point, and giving the excitation signal computed by the control unit of an actuator from an oscillating response calculation result It is desirable that it is what carries out the aforementioned oscillating response calculated-value coincidence of the response of an actuator after fixed time.

[0020] The vibration tester of the structure of this invention carries out object modeling of the part using thing or a model, other portions are numerical-model-ized, and an actuator is attached in a boundary portion with the numerical model of an object model. Moreover, the control unit of an actuator, The equipment which measures the reaction force from the object model produced in an actuator, and the digital computer which calculates the oscillating response of a numerical model, The equipment which measures the variation rate of the exciting point by the actuator, the equipment which measures speed, the equipment which measures acceleration, or its combination, The equipment which measures the variation rate of pieces other than the exciting point in an object model, or two or more points, the equipment which measures speed, the equipment which measures acceleration, or its combination, It is characterized by having a means to input reaction force measured value, and displacement, speed and an acceleration-measurement value into a digital computer, and a means to output the oscillating response calculated value of a digital computer to the control unit of an actuator.

[0021] In this case The reaction force from an object model as the sum of the reaction force proportional to the oscillating response equipped with the measuring device among displacement, speed, and acceleration of oscillating response measure points other than the oscillating response equipped with the measuring device among displacement, speed, and acceleration of an exciting point, and an exciting point Among the normal-mode-of-vibration vectors of the whole structure calculated by numerical-model-izing, an arbitrary piece or two or more arbitrary vectors, It is desirable to have a means to input into a digital computer the matrix which changes the physical space using the vector into mode space, the matrix which changes mode space into physical space, and an object model reaction force numerical model.

[0022] Moreover, the digital computer in this case The reaction force from the object model generated in an actuator

for every fixed time, the oscillating response with which the metering device of the displacement, speed, and acceleration of an exciting point is equipped, and the oscillating response equipped with the measuring device among displacement, speed, and acceleration of oscillating response measure points other than an exciting point are measured. The calculated value of reaction force is computed with an object model reaction force numerical model from measured value. The difference of reaction force measured value and reaction force calculated value is made into the external force value which joins an exciting point. the sum of an external force value and a known external force value It changes into the external force value in mode space by the physical space mode space conversion matrix. The mode response value after a fixed time unit is calculated with this mode space external force value. By changing a mode space response value by the mode space physics space conversion matrix, calculating the oscillating response after fixed time in an exciting point, and giving the excitation signal computed by the control unit of an actuator from an oscillating response calculation result It is desirable that it is what carries out oscillating response calculated-value coincidence of the response of an actuator after fixed time.

[0023] What differentiates a displacement measurement wave, the things which integrate with an acceleration measurement wave, or such combination of the speed metering device in each testing device of the above this invention are desirable. In this case, performing differential or integration numerically with the digital computer which has the I/O device of an analog wave, and a digital computer have desirable modes, such as being what is used for oscillating response calculation.

[0024] Moreover, the digital computer which performs the oscillating response in each above this invention testing device is a parallel computer to which it has two or more central processing units (it is hereafter indicated as CPU.), and calculation is performed in parallel, and it is desirable that it is that to which oscillating response calculation in two or more modes is performed simultaneously.

[0025] The vibration-test method of the structure of this invention carries out object modeling of some structures using thing or a model. The equipment which measures the reaction force from the object model which numerical-model-izes other portions, attaches an actuator in a boundary portion with the numerical model of an object model, and is produced in an actuator, With the digital computer equipped with a means to install the equipment which measures the variation rate of the exciting point by the actuator, and to input reaction force measured value and a displacement measurement value, and a means to output the oscillating response calculated value of a computer to the control unit of an actuator Beforehand the reaction force from an object model among the normal-mode-of-vibration vectors of the whole structure proportional to the variation rate of an exciting point calculated by numerical-model-izing An arbitrary piece or two or more arbitrary vectors, The matrix which changes the physical space using the vector into mode space, The reaction force from the object model generated in an actuator using the matrix which changes mode space into physical space, and an object model reaction force numerical model, and the variation rate of an exciting point are measured. The calculated value of reaction force is computed with an object model reaction force numerical model from a displacement measurement value. The difference of reaction force measured value and reaction force calculated value is made into the external force value which joins an exciting point. the sum of external force and a known external force value It changes into the external force value in mode space by the physical space mode space conversion matrix. By calculating the mode response value after a fixed time unit with this mode space external force value, and changing a mode space response value by the mode space physics space conversion matrix The variation rate after fixed time in an exciting point is calculated, and it is characterized by repeating outputting an excitation signal so that the variation rate may be realized to an actuator, and performing it.

[0026] Other this invention methods carry out object modeling of some structures using thing or a model, other portions are numerical-model-ized, and an actuator is attached in a boundary portion with the numerical model of an object model. Moreover, the control unit of an actuator, The equipment which measures the reaction force from the object model produced in an actuator, the equipment which measures the variation rate of the exciting point by the actuator, the equipment which measures speed, the equipment which measures acceleration, or its combination is installed. With the digital computer equipped with a means to input reaction force measured value, and the aforementioned displacement, aforementioned speed, and acceleration-measurement value, and a means to output oscillating response calculated value to the control unit of an actuator Used an arbitrary piece or two or more arbitrary vectors, and its vector among the normal-mode-of-vibration vectors of the whole structure calculated by numerical-model-izing reaction force from an object model beforehand as the sum of the reaction force proportional to what is equipped with the measuring device among displacement, speed, and acceleration of an exciting point. The matrix which changes physical space into mode space, and the matrix which changes mode space into physical space, A digital computer measures the oscillating response with which the metering device of the reaction force from the object model generated in an actuator, and the displacement, speed and acceleration of an exciting point is equipped for every fixed time using an object model reaction force numerical model. The calculated value of reaction force is computed with an object model reaction force numerical model from measured value, and the difference of reaction force measured value

and reaction force calculated value is made into the external force value which joins an exciting point. with a known external force value It changes into the external force value in mode space by the physical space mode space conversion matrix. The mode response value after a fixed time unit is calculated with this mode space external force value. By changing a mode space response value by the mode space physics space conversion matrix, calculating the oscillating response after fixed time in an exciting point, and giving the excitation signal computed by the control unit of an actuator from an oscillating response calculation result It is characterized by carrying out oscillating response calculated-value coincidence of the response of an actuator after fixed time.
[0027] Other this invention methods carry out object modeling of some structures using thing or a model, other portions are numerical-model-ized, and an actuator is attached in a boundary portion with the numerical model of an object model. Furthermore, the control unit of an actuator, The equipment which measures the reaction force from the object model produced in an actuator, and the digital computer which calculates the oscillating response of a numerical model, The equipment which measures the variation rate of the exciting point by the actuator, the equipment which measures speed, the equipment which measures acceleration, or its combination is installed. The equipment which measures the variation rate of pieces other than the exciting point in an object model or two or more points, the equipment which measures speed, the equipment which measures acceleration, or its combination is installed. With the digital computer equipped with a means to input reaction force measured value, and the aforementioned displacement, aforementioned speed, and acceleration-measurement value, and a means to output the oscillating response calculated value of a digital computer to the control unit of the aforementioned actuator Beforehand the reaction force from an object model as the sum of the reaction force proportional to the oscillating response equipped with the measuring device among displacement, speed, and acceleration of oscillating response measure points other than the oscillating response equipped with the measuring device among displacement, speed, and acceleration of an exciting point, and an exciting point Among the normal-mode-of-vibration vectors of the whole structure calculated by numerical-model-izing, an arbitrary piece or two or more arbitrary vectors, The matrix which changes the physical space using the vector into mode space, The matrix which changes mode space into physical space, and an object model reaction force numerical model are used. A digital computer measures the reaction force from the object model generated in an actuator, the oscillating response with which the metering device of the displacement, speed, and acceleration of an exciting point is equipped, and the oscillating response equipped with the measuring device among displacement, speed, and acceleration of oscillating response measure points other than an exciting point for every fixed time. The calculated value of reaction force is computed with an object model reaction force numerical model from measured value. The difference of reaction force measured value and reaction force calculated value is made into the external force value which joins an exciting point. the sum of an external force value and a known external force value It changes into the external force value in mode space by the physical space mode space conversion matrix. The mode response value after a fixed time unit is calculated with this mode space external force value. By changing a mode space response value by the mode space physics space conversion matrix, calculating the oscillating response after fixed time in an exciting point, and giving the excitation signal computed by the control unit of an actuator from an oscillating response calculation result It is characterized by carrying out oscillating response calculated-value coincidence of the response of an actuator after fixed time.
[0028] As for the mode vector which uses each vibration-test method of the above this invention for the numerical calculation of an oscillating response, it is desirable to choose only what has corresponding characteristic value smaller than the emission limitation which becomes settled by the technique used for oscillating response calculation and time serration, and it is [serration / time / of the numerical calculation of an oscillating response] desirable in taking small than the emission limitation which becomes settled from the maximum and the calculation technique of characteristic value corresponding to the mode vector used for the numerical calculation of an oscillating response
[0029]
[Function] Computational complexity required for the numerical analysis of an oscillating response is reduced by the modal analysis which performed the oscillating response of the structure for evaluation beforehand expressing in mode space, and removing the mode in which it does not have big influence on an oscillating response. Moreover, time serration can be enlarged by removing the small mode of a natural period. Consequently, test time can be shortened in a semi- dynamic test.
[0030] moreover, a vibration test also including the reaction force depending on the speed and acceleration of the substructure model which is a candidate for excitation can be performed by the ability being in agreement in the time-axis on calculation, and the time-axis on an excitation examination by shortening machine time according to the above-mentioned effect, and completing numerical calculation in calculation serration Moreover, since the stability condition is filled, oscillating response analysis is not emitted.
[0031]
[Example] Hereafter, according to a drawing, it explains about the example of this invention. Drawing 1 shows one

example of this invention typically. The substructure model 1 is installed on the foundation 11, and it excites with the actuator 2 fixed to the reaction force wall 10. The substructure model 2 is a part of whole structure model 9 which is expressed with a shear model as shown in drawing 2 , and portions other than substructure model 1 are numerical-model-ized, are inputted into a digital computer 7, and are used for calculation of an oscillating response.
[0032] The amount of displacement applied by the actuator 2 is the variation rate of the exciting point of a certain time calculated by the digital computer 7, a signal is given to the control unit 8 of an actuator through D/A converter 6 from a digital computer 7, and an actuator 2 drives it.
[0033] At this time, the displacement value of the load measuring instrument 3 and an exciting point is measured by the displacement measuring instrument 4, and incorporates the reaction force value from the substructure model 1 to a digital computer 7 through A/D converter 5.
[0034] Using this value, with a digital computer 7, when beforehand set by the algorithm shown later, it cuts fine in between, the displacement response after deltat is calculated, and a variation rate is again applied with an actuator 2.
[0035] When only the required number of times repeats the above-mentioned loop, oscillating behavior survey of the substructure model 1 and oscillating response evaluation of the whole structure model 9 are attained.
[0036] Next, the algorithm of the oscillating response calculation in this example is shown. Portions other than substructure model 1 are numerical-model-ized among the whole structure models 9. That is, it becomes the one equation of motion.
[0037]
[Equation 1]

$$[M]\{\ddot{x}\}+[C]\{\dot{x}\}+[K]\{x\}=\{f\}+\{q\} \quad \cdots(数1)$$

ここに　[M]：数値モデルの質量マトリクス
[C]：数値モデルの減衰マトリクス
[K]：数値モデルの剛性マトリクス
{x}：数値モデルの変位ベクトル
{q}：加振点における実物モデルからの反力ベクトル
ただし、加振点に対応する要素以外は０
{f}：既知の外力項、たとえば地震力など
・：時間に関する微分

[0038] ** -- an inner constant matrix [M], [C], and [K] are defined beforehand
[0039] Furthermore, reaction force from the substructure model 1 which actually examines is numerical-model-ized to alignment about the variation rate of an exciting point. That is, it is set to several 1.
[0040]
[Equation 2]

$$\{q'\}=-[K']+\{x\} \quad \cdots(数2)$$

ここに　[K']：実物モデルの剛性マトリクス
ただし、加振点に対応する要素以外は０
{q'}：反力ベクトルの線形化モデル

[0041] And {q'} is substituted as {q} of several 1. That is, it is set to several 3.
[0042]
[Equation 3]

$$[M]\{\ddot{x}\}+[C]\{\dot{x}\}+([K]+[K'])\{x\}=\{f\} \quad \cdots(数3)$$

[0043] This right-hand side is set with 0, and characteristic value and the native mode are searched for by well-known technique. The native mode as been this, for example, shown in drawing 3 is searched for.
[0044] The displacement vector of the physical space of several 2 is changed into a mode space vector by the native mode matrix made by this native mode.
[0045]
[Equation 4]

$\{u\}=[\Phi]^T\{x\}$ …(数4)

ここに　$\{u\}$：モード空間ベクトル

$[\Phi]$：固有モードマトリクス

ただし

$[\Phi]=[\{\phi_1\},\ \{\phi_2\},\ \cdots\{\phi_i\}\cdots,\ \{\phi_n\}]$

$\{\phi_i\}$：i次の固有モード

n：$\{x\}$の次元数

[0046] Moreover, a mode space vector is conversely convertible for physical space.
[0047]
[Equation 5]
$\{x\}=[\Phi]\{u\}$ …(数5)

[0048] These native modes are not necessarily required reasons altogether at calculation of an oscillating response. For example, when it is the mode which cannot be easily excited by the external force expected, even if it is separated from the frequency domain of the external force the resonant frequency is expected to be, or it analyzes except for them, it is almost satisfactory. Then, several 5 can be approximated using the reduction native mode matrix except these modes.
[0049]
[Equation 6]
$\{x\}\approx[\overline{\Phi}]\{\overline{u}\}$ …(数6)

$[\overline{\Phi}]$：縮小固有モードマトリクス

ただし

$[\overline{\Phi}]=[\{\overline{\phi}_1\},\ \cdots\{\overline{\phi}_i\}\cdots,\ \{\overline{\phi}_m\}]$

$\{\overline{\phi}_i\}$は$\{\phi_1\},\ \cdots,\{\phi_n\}$のいずれかであり

$i\neq j$のとき　$\{\overline{\phi}_i\}\neq\{\overline{\phi}_j\}$

また　$m\leq n$

$\{\overline{u}\}$：縮小モード空間ベクトル

[0050] By the way, several 2 difference produces the reaction force from the measured actual substructure model 1 according to nonlinearity or the error of modeling. That is, it is shown by several 7.
[0051]
[Equation 7]
$\{q\}=\{q'\}+\{\Delta q\}$ …(数7)

ここに

$\{\Delta q\}$：反力ベクトルの実測値と計算値の誤差

[0052] Then, several 3 becomes as the following formula.
[0053]
[Equation 8]
$[M]\{\ddot{x}\}+[C]\{\dot{x}\}+([K]+[K'])\{x\}=\{f\}+\{\Delta q\}$ …(数8)

[0054] That is, even if it thinks that the linear model of the reaction force of the substructure model 1 and the error of an actual measurement contribute as external force in an exciting point, it does not interfere.
[0055] If several 1 is changed using the reduction native mode matrix of several 5, it will become the following formula by defining an attenuation matrix suitably.
[0056]

[Equation 9]
$$\{\ddot{\bar{u}}\}+[\dot{Z}]\{\dot{\bar{u}}\}+[\Omega^2]\{\bar{u}\}=[\bar{\Phi}]^T(\{f\}+\{\Delta q\}) \quad \cdots(数9)$$

ここに、

$$[Z]=[\bar{\Phi}]^T[C][\bar{\Phi}]=\begin{pmatrix} 2\zeta_1\omega_1 & & 0 \\ & \ddots & \\ 0 & & 2\zeta_m\omega_m \end{pmatrix}$$

$$[\Omega^2]=[\bar{\Phi}]^T([K]+[K'])[\bar{\Phi}]=\begin{pmatrix} \omega_1^2 & & 0 \\ & \ddots & \\ 0 & & \omega_m^2 \end{pmatrix}$$

ただし、固有ベクトルは

$$[\bar{\Phi}]^T[M][\bar{\Phi}]=[I]$$

であるように規格化されており、

ζ_i : i次モードの減衰比

ω_i : i次モードの固有円振動数

[0057] In addition, when the number of the vectors to be used is one, a matrix and a vector serve as a scalar. Since the matrix of left part is diagonalized, if external force becomes settled, the response in each mode can be solved independently. That is, several 10 can show.
[0058]
[Equation 10]
$$\ddot{u}^K+2\zeta_K u_K \dot{u}^K+\omega_K^2 u^K=\{\bar{\phi}_K\}(\{f\}+\{\Delta q\}) \quad \cdots(数10)$$

ここに

$\ddot{u}^K$, $\dot{u}^K$, u^Kは$\{\ddot{u}\}$, $\{\dot{u}\}$, $\{u\}$のK番め要素

[0059] This formula is minced time and it solves numerically to every deltat. For example, the following technique can be considered. This applies the technique called centered-difference method. The response in the k-th mode in a certain time ti is as the following formula from several 10.
[0060]
[Equation 11]
$$\ddot{\bar{u}}_i^K+2\zeta_K\omega_K\dot{\bar{u}}_i^K+\omega_K^2\bar{u}^K=\{\bar{\Phi}_K\}(\{f_i\}+\{\Delta q_i\}) \quad \cdots(数11)$$

[0061] Speed and acceleration are approximated by the following formula under assumption of acceleration regularity by Time ti order **deltat.
[0062]
[Equation 12]
$$\left.\begin{aligned} \ddot{\bar{u}}_i^K &= (2\bar{u}_i^K-\bar{u}_{i-1}^K-\bar{u}_{i+1}^K)/\Delta t^2 \\ \dot{\bar{u}}_i^K &= (\bar{u}_{i+1}^K-\bar{u}_{i-1}^K)/2\Delta t \end{aligned}\right\} \quad \cdots(数12)$$

[0063] If this is substituted for several 11 and it solves about the variation rate of time ti+1, it will become like several 13.
[0064]
[Equation 13]

$$\overline{u}_{i+1}^{K} \doteq [2\overline{u}_{i}^{K} - \overline{u}_{i-1}^{K} + \zeta_K \omega_K \Delta t \overline{u}_{i-1}^{K} - \Delta t^2 \{\omega_K^2 - \{\overline{\Phi}_K\}(\{f_i\} + \{\Delta q_i\})\}]/(1 + \zeta_K \omega_K \Delta t) \quad \cdots(数13)$$

[0065] Therefore, if the external force term {fi} in Time ti defined beforehand, the linear model of the reaction force from the substructure model 1, and the difference {deltaqi} of survey are known, the mode response in time ti+1= ti+delta t will be calculated.
[0066] the exciting point in Time ti since a linear model can be described like several 2 -- the error of reaction force is calculated by the following formula from the actual measurement of a variation rate
[0067]
[Equation 14]

$$\{\Delta q\} = \{q'\} + [K']\{x\} \quad \cdots(数14)$$

[0068] however -- since [K'] is 0 except the element corresponding to an exciting point -- {x} -- an exciting point -- only a variation rate is required
[0069] In addition, even if the calculation method of a response of time ti+1 uses not only the above-mentioned technique but other technique, it does not interfere.
[0070] If the response in each mode is calculated by the above, when a physical space vector transforms a mode space vector inversely, the variation rate of time ti+1 will be computed.
[0071] It is shown by this, several 15 [i.e.,].
[0072]
[Equation 15]

$$\{x_{i+1}\} = [\Phi]^T \{\overline{u}_{i+1}\} \quad \cdots(数15)$$

[0073] However, it is necessary to ask for no variation rate of the joints of a numerical model, and only required points, such as a variation rate of an exciting point, can also be calculated in this calculation. That is, it is several 16.
[0074]
[Equation 16]

$$x_{i+1}^{l} = [\overline{\Phi}_l]^T \{u_{i+1}\} \quad \cdots(数16)$$

ただし、l は振動変位を評価する点の要素番号

[0075] The following procedures perform applying the above algorithm to an examination. First, before examining, the mode is beforehand computed by several 1-3, and according to the flow shown in drawing 4 , it examines hereafter using the result.
[0076] The reaction force from the substructure model 1 in introduction and Time ti is measured with the load measuring instrument 3. Next, the variation rate of an exciting point is measured with the displacement measuring instrument 4. Whether it is reverse or the sequence of these measurement is simultaneous, it does not interfere. Next, the error of the reaction force in an exciting point is computed with a-14 number from the measurement value of a variation rate, and the actual measurement of reaction force.
[0077] The value in the error of this reaction force and the time ti of the external force which should evaluate the oscillating response of the whole structure model 9 is changed into reduction mode space by the several 9 right-hand side. The response in the mode is calculated by several 13 using the external force in this mode space.
[0078] The variation rate of an exciting point is calculated with a-15 number from the response value in each mode. The driving signal of an actuator is outputted so that this variation rate may be realized. After a variation rate is realized by the actuator, only deltat recommends time serration and it returns to measurement of the above-mentioned reaction force. The vibration test of the object structure can be performed by only the required number of's times repeating the above and performing it.
[0079] In carrying out this examination, a timetable as shown in drawing 5 is followed. Since the reaction force from the substructure object model 1 is modeled as an amount only depending on a variation rate, the time-axis in an examination does not need to be in agreement with the time-axis in calculation, and even if the time-axis in an examination is extended by response calculation by the computer, and the drive of an actuator on the time-axis in calculation, they are not hindered by time at this time.
[0080] According to this example, since the small mode of the contribution to a response is removable in response calculation, the computational complexity of response calculation becomes small. Moreover, since the short mode of a

natural period is removable, time serration of response calculation can be enlarged. Therefore, it is effective in the ability to shorten test time.
[0081] Next, another example is shown using drawing 6 . In addition to displacement measuring instrument 4a, the example of drawing 6 installs speed measuring instrument 4b and acceleration measuring instrument 4c in an example as equipment which measures the state of a substructure model at drawing 1 . It can examine, when the reaction force which depends for this equipment on acceleration and speed from the substructure model 1 by performing a vibration test and oscillating calculation according to the following algorithms is added.
[0082] Although the calculation technique is the same as that of the aforementioned example almost, a different point is shown below. First, reaction force from the substructure model 1 is linear-model-ized. At this time, a model is made by several 17 instead of several two.
[0083]
[Equation 17]

$$\{q'\} = -([M']\{\ddot{x}\} + [C']\{\dot{x}\} + [K']\{x\}) \quad \cdots (数17)$$

[0084] In addition, what is necessary is not to use all displacement, the speed, and acceleration, and to use only a required oscillating response with the property of a substructure model in modeling. And what is necessary is to measure only the oscillating response used in several 17. This point is the same although explained required [all displacement, the speed, and acceleration] in other examples described below.
[0085] Several 17 is substituted for several 1, characteristic value analysis is performed like the aforementioned example, and a native mode vector is searched for. In this case, the error of reaction force uses several 18 instead of several 14.
[0086]
[Equation 18]

$$\{\Delta q\} = \{q\} + [M']\{\ddot{x}\} + [C']\{\dot{x}\} + [K']\{x\}) \quad \cdots (数18)$$

[0087] The algorithm in the case of examining using this calculation technique is explained.
[0088] First, before examining, the mode is beforehand computed by several 1, 3, and 17, and according to the flow shown in drawing 7 , it examines hereafter using the result.
[0089] The reaction force from the substructure model 1 in introduction and Time ti is measured using measuring instruments 4a, 4b, and 4c. Next, the oscillating response of the displacement, speed, and acceleration of an exciting point is measured. These measurement is simultaneously performed at Time ti.
[0090] Next, the error of reaction force is computed by several 18. The value in the time ti of the external force which should evaluate the oscillating response of the error of this reaction force and the whole structure model 1 is changed into reduction mode space by the several 11 right-hand side.
[0091] The response in the mode is calculated by several 13 using the external force in this mode space. The oscillating response of an exciting point is calculated with a-15 number from the response value in each mode. The driving signal of an actuator 2 is outputted so that this oscillating response may be realized after deltat from the time ti which measured the oscillating response of the displacement, speed, and acceleration of an exciting point.
[0092] And it returns to measurement of an oscillating response of reaction force, and displacement, speed and acceleration after deltat again. The vibration test of the object structure can be performed by only the required number of's times repeating the above and performing it.
[0093] In carrying out this examination, a timetable as shown in drawing 8 is followed. Since the reaction force from the substructure object model 1 is modeled as an amount not only depending on a variation rate but speed and acceleration, the time-axis in an examination needs to be in agreement with the time-axis in calculation. Therefore, it is necessary to cut fine the time in calculation and to perform oscillating response calculation of the following step between deltat.
[0094] According to this example, since the small mode of the contribution to a response is removable in response calculation, the computational complexity of response calculation becomes small. Furthermore, since the short mode of a natural period is removable, time serration of response calculation can be enlarged. Therefore, it becomes possible to cut fine time and to end response calculation between deltat. Moreover, it becomes possible to perform a vibration test by the real time according to the above-mentioned effect, and when the reaction force depending on speed or acceleration is contained in reaction force from the substructure model 1, operation of an examination is attained.
[0095] in addition, the speed measuring instrument of drawing 7 shows it to integrating with acceleration, as shown in drawing 9 , and drawing 10 rather than detects direct speed -- as -- a variation rate -- differentiating a signal -- or it is good also as such combination An integrator and a differentiator may use the digital computer which may use an analog circuit and has an A/D converter and a D/A converter. Furthermore, you may perform integration or differential

within the digital computer 7 which performs response calculation.
[0096] Furthermore, drawing 11 explains another example. Let the digital computer 7 currently used for the two aforementioned examples be a parallel computer in this example. Drawing 11 shows how to share calculation with two or more CPUs as a time history. external force -- and -- virtual -- external force -- CPU (m+1) -- 15 -- having carried out -- after -- a response -- calculation -- using it -- having -- m -- a piece -- the normal mode of vibration -- a response -- calculation -- parallel -- CPU -- (-- one --) -- 12 -- CPU -- (-- two --) -- 13 -- a shell -- CPU -- (-- m --) -- 14 -- up to -- carrying out .
[0097] The result is changed into physical space by CPU (m+1)15. Response machine time can be shortened by making it this composition, and test time can be shortened in the first example, and the 2nd example **** becomes possible [cutting fine time easily and ending response calculation between deltat].
[0098] In the above-mentioned example, although the substructure model 1 was the portion connected with the foundation of the whole structure model 9, even if they are other portions, it does not interfere. For example, as shown in drawing 12 , you may be the interstitial segment of the structure.
[0099] In the case of the 1st example, since it is dependent only on the relative displacement of the boundary of the substructure model 1 and a numerical model, the substructure model 1 can be examined by composition as shown in drawing 1 . What is necessary is to make an exciting point into two places and just to consider as composition like drawing 13 in the 2nd example, since it is dependent also on speed and acceleration besides a relative displacement.
[0100] Moreover, what is necessary is to make the lower actuator 2 into the shake table 19 supported by bearing 16, and just to consider as composition like drawing 14 , when the self-weight of the substructure model 1 is large. It is better to consider as such composition, when acceleration influences greatly also in the case of a substructure model 1 like drawing 2 .
[0101] Moreover, the case where the substructure model 1 hits at the nose of cam of the whole structure model 9 like drawing 15 in the 2nd example is sufficient. In this case, a substructure model will be carried in the shake table supported by bearing 16 like drawing 16 , and acceleration excitation will be performed. In the case of this substructure model, it will linear-model-ize using displacement, speed, and acceleration at not only displacement, speed, and acceleration of an exciting point but a nose of cam. That is, it is several 19 passage.
[0102]
[Equation 19]

$$\{Q\}' = -([M']\{\ddot{y}\}+[C']\{\dot{y}\}+[K']\{y\}) \qquad \cdots(数19)$$

ここに、$\{y\}^T = \{\{x\}^T,\ x_T\}$

ただし、x_T：先端の変位

[0103] Then, in order to calculate the calculated value of reaction force, the measuring instruments 4a, 4b, and 4c at a nose of cam also perform measurement of displacement, speed, and acceleration like drawing 16 , and it substitutes for several 17. In addition, the equation of motion used at this time is not several 1 but several 20.
[0104]
[Equation 20]

$$\begin{bmatrix} [M] & \{O\} \\ \{O\}^T & 0 \end{bmatrix}\{\ddot{y}\} + \begin{bmatrix} [C] & \{O\} \\ \{O\}^T & 0 \end{bmatrix}\{\dot{y}\} + \begin{bmatrix} [K] & \{O\} \\ \{O\}^T & 0 \end{bmatrix}\{y\} = \begin{Bmatrix} \{f\} \\ 0 \end{Bmatrix} + \{Q\} \qquad \cdots(数20)$$

ただし、$\{O\}$は、すべての要素が0であるn次元ベクトル

[0105] Furthermore, drawing 17 and drawing 18 explain another example. It may be better to make a model using displacement, speed, and acceleration of not only displacement, speed, and acceleration of an exciting point but a midpoint like drawing 17 , when the linear model of a substructure model is created. At this time, several 21 can show the linear model of reaction force.
[0106]
[Equation 21]

$\{Q\}' \doteqdot -([M']\{\ddot{y}\}+[C']\{\dot{y}\}+[K']\{y\})$ …(数21)

ここに、$\{y\}^T=\{\{x\}^T,\ x_{M1},\ \cdots,\ x_{Mp}\}$

x_{Mi} ：中間点ｉの変位

p ：中間点の個数

[0107] In this case, as shown in drawing 18 , displacement, speed, and acceleration of not only displacement, speed, and acceleration of an exciting point but a midpoint are measured with measuring instruments 4a, 4b, and 4c, and the calculated value of reaction force is calculated.
[0108] Except place [whose algorithm timetable uses the actual measurement of the displacement, speed, and acceleration of not only the actual measurement of the displacement, speed, and acceleration of an exciting point but a midpoint for calculation of reaction force], it is the same as the 2nd example. In this case, the equation of motion is expressed with several 22.
[0109]
[Equation 22]

$$\begin{pmatrix} [M] & [O'] \\ [O']^T & [O] \end{pmatrix}\{\ddot{y}\}+\begin{pmatrix} [C] & [O'] \\ [O']^T & [O] \end{pmatrix}\{\dot{y}\}+\begin{pmatrix} [K] & [O'] \\ [O']^T & [O] \end{pmatrix}\{y\}$$

$$=\left\{\begin{matrix}\{f\} \\ \{O\}\end{matrix}\right\}+\{Q\} \quad \cdots(数22)$$

ただし、$[O']$：すべての要素が０であるｐ×ｎマトリクス

$[O]$ ：すべての要素が０であるｐ×ｐマトリクス

$\{O\}$ ：すべての要素が０であるｐ次元ベクトル

[0110] According to this example, an examination becomes possible also as a candidate for excitation about the quite complicated substructure model 1.
[0111] The structure made applicable to an examination may be what [not only] can be expressed as a shear model as shown above but what configuration. For example, what is necessary is just to consider as composition like drawing 20 to structure as shown by drawing 19 . In this case, the actuator for excitation has flexibility required for linear-modelizing of a substructure model, and its same is said of a load and oscillating response measurement.
[0112] Therefore, it is necessary to be able to perform excitation of 6 flexibility per the maximum and exciting point, and for measurement of reaction force and measurement of an oscillating response to be also able to perform measurement of 6 flexibility. For that purpose, for example, it is necessary to use 6 flexibility actuator as shown in drawing 21 . It consists of 6 actuator 20a-20f and 6 bearing 21a-21f, and the displacement sensor and the load sensor are installed in each actuator, and a variation rate and reaction force can be changed into the coordinate which made numerical calculation by matrix calculation and has been required. Of course, what is necessary is just to consider as the configuration according to it, when there may be little flexibility of an actuator.
[0113] Moreover, configuration is not necessarily limited to what was shown in the above-mentioned example, and can take various composition in the range which does not deviate from the main point of this invention.
[0114] Furthermore, another example is shown. The stability condition which becomes settled by the numerical calculation technique exists in numerical analysis. For example, in the describing [above] centered-difference method, the following formula is a stability condition.
[0115]
[Equation 23]

$$\Delta t \leq \frac{T}{\pi} \quad \cdots(数23)$$

ここに、Δt ：時間刻み

T ：最小固有周期

[0116] Therefore, among the modes which mince time and are used for deltat and numerical calculation, it is necessary to set up the minimum natural period T so that several 23 may be filled.
[0117] When time serration is determined from the capacity of a computer etc., in selection in the mode used for

numerical calculation, it chooses so that the minimum mode natural period may fill several 23 to the minimum time serration.
[0118] Moreover, when the mode needed from the configuration in the vibration frequency range of an input or the mode becomes settled, time serration is set up so that several 23 may be filled to the minimum mode natural period.
[0119] By examining on these conditions, it is effective in the ability of numerical analysis, therefore a vibration test to carry out stably.
[0120]
[Effect of the Invention] Since according to this invention computational complexity of numerical calculation can be lessened in some vibration tests of the structure, and the vibration test performed combining the oscillating response numerical analysis of other portions and time serration on calculation can be made small, test time can be shortened.
[0121] Moreover, on the other hand, it can examine by the real time more to computational complexity reduction, expansion of time serration, and parallelization of calculation, and the examination which evaluated the reaction force for which it depended on speed and acceleration from the substructure is attained.

[Translation done.]